Paper

Delays in Technology Development: Their Impact on the Issues of Determinism, Autonomy and Controllability of Technology

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Abstract—The paper provides a discussion of diverse delays occurring in technology development, and an explanation of reasons why, when seen holistically from outside, the process of technology development might appear as an autonomous, self-determining, uncontrollable process. When seen from inside, however, the process is far from being uncontrollable. This paradox is explained by the fact that technology development contains many processes with delays, in total amounting sometimes to fifty years; when seen from outside, such a process might appear uncontrollable, even if it is very much controllable when approached internally and in detail. Therefore, the definition and types of technology creation as well as stages of technological processes are discussed in some detail in this paper. Some aspects of the contemporary informational revolution and some recent results on micro-theories of knowledge and technology creation are also reviewed. It is suggested that one of possible ways of changing the paradigmatic attitude of philosophy of technology is to invite some such philosophers to participate in the development of modern tools of knowledge civilization era, such as software development and evaluation. The conclusions of the paper stress the need of essentially new approaches to many issues in the time of informational revolution.

Keywords*— *autonomy, change of episteme, delay time, determinism and controllability of technology, impacts of informational revolution, paradigm of philosophy of technology, technology development and evaluation.

1. Introduction

Seemingly and actually, software development and evaluation is very distant from philosophy of technology. Software development and evaluation is detailed, specific, motivated by the goal of producing best, reliable and user-friendly software, applies specific staged development and evaluation processes as well as software quality criteria; it requires deep specialized knowledge about software engineering, and is future-oriented, concentrates *ex ante* on new products. Philosophy of technology is general, sees technology as a socio-economic system of producing and utilizing products of technology; sometimes accuses this system of being autonomous or deterministic – that is, developing according to its inner momentum, without taking into account humanistic values; often accuses this system of being unethical – underestimating technological risks; is historically oriented, concentrates on *ex post* evaluation of results of technological development.

Yet this does not mean that the visible gap between software evaluation and philosophy of technology is justified; nor that it is desirable. Software development will (or already has) become the decisive factor in the development of technology; also, it contributes to technological risks. Without including aspects of philosophy of technology, software evaluation is liable to be accused of *technological, instrumental and functional rationality*[1]; more seriously speaking, inputs from philosophy of technology might enrich software development and evaluation. On the other hand, without participating in software development, particularly in software evaluation, in times of information revolution, philosophy of technology runs the risk of becoming outdated and sterile. The conclusion is that both sides might gain by bridging the gap. However, we shall see that the initiative must come from software engineering side, simply because philosophy of technology is too paradigmatic – and I am telling this both as a technologist, since fifty years specializing in computer simulation and diverse related aspects of information technology, and a specialist working in recent years close to philosophy, on the new micro-theories of knowledge and technology creation.

This too paradigmatic attitude of philosophy of technology can be best illustrated by the opinion of Val Dusek [1], a leading humanist philosopher of technology, who even today denies the concept of informational revolution and calls all the discussion of the change of civilization era, of postindustrial, postcapitalist, informational or networked society a *technocratic hype* and *technological determinism*. On the other hand, as shown, e.g., in [2], the evidence of tremendous social and economic changes already occurring due to the impact of computing and network technology is obvious. We might add here that the automation and robotization of manufacturing already resulted in advanced countries in an essential *dematerialization of work* which contributed to the de-legitimization of the Marxian concept of the leading role of proletariat and thus to the fall of communist system. Thus, positions denying the change observed today correspond to closing eyes when spotting unpleasant objects. It might be related to an intuitive, unpleasant perception that if the thesis about an informational

[1] I just quote here typical phrases of philosophy of technology, even if I disagree with their meaning and use – because personally I see *technology as the art of creating tools*, in a broad sense including software, and refuse to accept the reduction of creative technological rationality to instrumental and functional aspects.

revolution leading to a new era is valid, then the classical philosophy of technology does not have a chance: it must address quite new themes and must ask technologists about advice, while it succeeded until now to concentrate on the criticism of the old industrial society and develop practically without any feedback from engineers.

Thus, the motivation of this paper is to outline a list of new topics of philosophy of technology, important in the times of informational revolution and the beginnings of a new era. We should start, however, with a criticism of a myth of old philosophy of technology, concerning the assumed (arbitrarily and intuitively, thus deeper than paradigmatically – actually, in the hermeneutical horizon[2] of old philosophy of technology) autonomy and determinism of technology.

2. The Reasons of Seeing Technology as an Autonomous, Deterministic System

We should recall first that the old philosophy of technology understands its object, the concept of *technology*, in diverse meanings (often without specifying the meaning used in a given discourse), but most often *as the socio-economic system of creating and utilizing products of technology or technological artefacts approached holistically*, while technologists tend to understand their field more narrowly, as *the art of creating tools and technological artefacts*. However, we shall discuss these distinctions in more detail later, here we concentrate on the properties of the socio-economic technological system. This system was often seen by the old philosophy of technology as autonomous, i.e., uncontrollable in technical terms, and deterministic, in at least two senses: self-determining (which is similar to autonomous) or determining the development of society. The latter is an obvious error when seen by a technologist who knows well that *technology proposes and society chooses*, although historically we can list such technological developments (Johann Gutenberg, James Watt, personal computers and computer networks) that *enabled* great economic, social and cultural changes; thus, *technology does not determine*, *only enables social changes*. The issue of self-determination and autonomy or uncontrollability of technology is more complicated, however.

The socio-economic system of creating and utilizing products of technology is complex. By approaching it holistically, without analyzing in detail its parts and their relations, the impression that this system is autonomous and self-determining is very likely to emerge. The most important reason for that impression might be the fact – overlooked by most philosophy of technology – that *this system includes many delays*. By delay we understand the time interval between starting an activity and observing its' results; obviously, in the development of technology we can observe at least the delay between starting a design and finishing it, including initial testing and evaluation. However, this delay is relatively small when compared to other delays in the processes of social acceptance and market penetration of products of technology. At the very beginning, new technological ideas appear often in academic communities; the character of knowledge creation in these communities is different than in industrial research organizations, see [4], [5] and Section 4 of this paper; this makes difficult the transfer of ideas from academia to industry and induces additional delays.

Even if a product is ready for market penetration, consumers initially distrust new products; it needs time to develop social demand. Moreover, oligopolistic firms on high technology markets delay acceptance of new standards, trying to preserve this way their markets shares; this is another reason of delays. These diverse socio-economic reasons increase the total delay between an original idea and its broad socio-economic use. *In the case of mobile cell telephony this delay amounted to fifty years* (the principle was developed for military purposes during the Second World War in the forties, broad social use occurred in the nineties of the 20th century). In the case of transistors and integrated circuits the delay was shorter, because of their importance in the time of cold war; but in the case of digital television the delay again exceeds fifty years. For other examples of such delays, see [6].

Now, a system with delays, if approached holistically from outside, very likely appears as autonomous and self-determining; we seem to have lost control over its functioning. This is very well known to specialists in control of systems with delays[3], but might require a more detailed explanation for non-specialists. Delay is a concept from systems dynamics, better known to technological systems dynamics studying systems with both inertial and pure delays than to sociological systems dynamics that by delays understands mostly inertial delays. By inertial delay we mean delay occurring as a result of accumulation processes, such as filling a glass with water; you can try to control it by increasing the volume of the stream of water. By pure delay we mean delay due to transportation, such as the delay occurring when you wait on an airport at a luggage conveyor, say, the delay between your luggage appearing on the conveyor and its' coming to the place where you wait for it. If you cannot move towards your luggage, you obviously lose control over it until it comes to your place.

Thus, when approaching from outside a socio-economic system with delays coming to fifty years, you certainly perceive a loss of control over the system. But how to ef-

[2]By a *hermeneutical horizon*, as specified more precisely in [3] though used earlier in diverse writings of hermeneutical philosophy, we understand a*n intuitively assumed system of beliefs in the truth of basic axioms*. A hermeneutical horizon is usually not expressed explicitly, but can be reconstructed, i.e., inferred from diverse clues. A hermeneutical horizon is thus an intuitive, deep foundation of a paradigm.

[3]Such as myself: long ago, I have worked intensively on industrial control of processes with delays and published in 1970 a paper on the maximum principle (a necessary condition of optimality of dynamic control) for systems with non-trivial pure delays in control, see [7].

fectively control systems with delays? There are several ways known to specialists; all of them, however, reduce to trying to anticipate its behavior, or at least measure or acquire information about this behavior with less delay than in the end effect. In the example with airport luggage conveyor, this amounts to choosing such a place that you can observe your luggage from the moment of its appearance on the conveyor and react appropriately when it falls down from the belt, or is taken by mistake by another passenger. How to use this analogy for controlling the development of technology? We must simply abandon the holistic, outside approach, analyze the details of the development and see in which points, at what stages of the process we can obtain anticipating information.

Therefore, we must simply abandon the position originated by a classical author of philosophy of technology, Jacques Ellul [8], limiting his interests to collective processes in the society that must be approached holistically, and followed – for diverse reasons – by most philosophers of technology. For example, Carl Mitcham [9, p. 65] argues that humanist philosophers, dominating philosophy of technology[4], simply cannot learn the details of technology, because "becoming mired in the specialized details of technology and its many processes tends to obscure relationships to nontechnological aspects of the human". However, *the main point of this paper is that we have here a binary, either-or choice*: either philosophers of technology continue to abstain from going into details of the process of technology creation, thus they will continue to see technology as a dark, uncontrollable force; or they will try to cooperate in effective control of technology, but then they must learn details. Such learning of details starts with the definition of technology and stages of technological processes.

3. What Is Technology and Stages of Technology Creation and Utilization

We can start by asking the question: *what is technology*? There are diverse answers to this question. Technology might be:

- for a philosopher of technology: *the socio-economic system of creating and utilizing technology*;
- for a postmodern humanist scientist: *an autonomous force enslaving humanity*;
- for an economist: *a way of doing things, a technical process*;
- in common language: *a technical artefact*;
- for a natural scientist: *an application of scientific theories*;
- for a technologist: *the art of constructing tools, an inherent faculty of humanity, motivated by the joy of creation*:
  - *liberating* people from hard work;
  - *helping* technology brokers (venture capitalists, bankers, managers) to make money – and if any effect of that is *enslaving*, the brokers are responsible;
  - *stimulating* the development of hard science by *inventions* which give it new principles to develop new concepts.

If there are that many answers, this means that the word *technology* is commonly used imprecisely, such as in common language it often means *a technological artefact*, while I rather use the term *product of technology* to denote this meaning. Being a technologist, I believe that our, technological understanding is most close to the essence[5] of the meaning of the word technology; however, since others might contend this interpretation (and Dusek [1] does not even list it in his discussion of definitions of technology), I agree to designate it *technology proper*. Moreover, it is very close to one of interpretations of the word technology by Martin Heidegger [10] – even if he used several such interpretations, selecting a convenient interpretation for a given discourse – as well as to the classical Greek word *techne*. In [11] and [12] the following definition was proposed:

Technology proper is a basic human faculty that concentrates on the creation of tools and artefacts needed for humanity in dealing with nature. It presupposes some human intervention in nature, but can also serve the goal of limiting such intervention to the necessary scale. It is essentially a truth-revealing, creative activity, thus it is similar to arts. It is also, for the most part, a problem-solving activity, concentrating on solving practical problems.

Philosophy of technology often says that the old concept of techne was changed by modern mass production, but this is mixing technology proper with mass production technological processes that constitute another stage of the socio-economic system of technology creation and utilization. Techne, technology proper, remains essentially the same: a truth-revealing, creative activity of constructing tools – naturally, tools characteristic for a given civilization era; we can speak thus about $techne_1$ in ancient Greece, $techne_2$ in the times of constructing telescopes and mechanical clocks, $techne_3$ in the era of industrial civilization, $techne_4$ in times of informational revolution and knowledge civilization, when the main tools constructed are software tools.

Now we should outline shortly – see [5] for a more detailed discussion – the relations of technology proper to hard science (natural sciences and mathematics) and to soft science (social sciences and humanities), as well as to the system

[4]Philosophers of mathematics are almost all – with a few exceptions – mathematicians; philosophers of technology are almost all – with even fewer exceptions – humanists or sociologists, not technologists.

[5]With all reservations concerning the possibility or rather impossibility of reaching the true essence of meanings.

of socio-economic applications of technology. They are outlined by the second part of the definition:

Thus, technology proper uses the results of basic sciences, if they are available; if they are not, technology proposes its own solutions, often promoting in this way quite new concepts, which are assimilated after some delay by the hard or social sciences. It is not an autonomous force, because it depends on all other human activities and influences them in return. It is, however, sovereign, in the same sense as arts are sovereign human activities. Autonomous forces can be found in the socio-economic system of applications of technology proper.

How, then, do the hard, basic sciences and technology depend on each other? As in many questions of human development, they influence each other through a positive feedback loop, see Fig. 1; technological development stimulates basic science, while scientific theories are applied technologically.

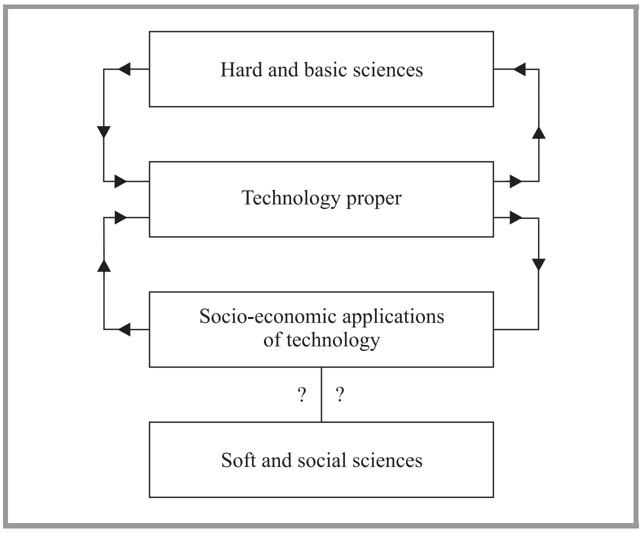

Fig. 1. Two positive feedback loops.

Recall that feedback – the circular impact of the time-stream of results of an action on its causes – was used by James Watt in a negative feedback loop and reinvented by Harold Black [13][6]. Feedback can be of two types: positive feedback when the results circularly support their causes, which results in fast development, like a growing avalanche, and negative feedback when the results circularly counteract their causes, which leads to the positive effect of stabilisation (for example, the stabilisation of human body temperature is based on negative feedback). The concept of feedback essentially changed our understanding of the cause and effect relationship, resolving paradoxes of circular arguments in logic (when they concern causal reasoning), though it must be understood that such paradoxes can be resolved only by dynamic, not static causal reasoning or models. An example of such paradox is the argument of Bruno Latour [14] against objectivity, saying that since the concept of nature is the outcome of our construction of knowledge, it cannot be at the same time its cause – a clear example of a deep misunderstanding of the essentially dynamic, evolutionary character of the causal positive feedback loop in this case.

But the positive feedback loop between technology and science works slowly: technological stimulations are analyzed by science with much delay, and technology also does not reply instantly to new scientific theories.

The second positive feedback loop is between technology and the systems of its socio-economic applications. The distinction between technology proper and its socio-economic applications should be obvious for at least two reasons. The first is that technologists often work on a technological problem for quite a long time (e.g., almost fifty years in the case of digital television) before their results are broadly socially applied. The second is simple: *technologists do not make much money, technology brokers* (entrepreneurs, managers, bankers, etc.) *do*, just as art brokers make more money than artists. If a technological product or service, such as mobile telephony, produces much revenue, then more money is available for its further technological development; this leads to the truly avalanche-like processes of the social adoption of technological hits.

These processes have strange dynamic properties, socio-economic acceptance of novelties is slow, and there is usually a long delay time between the recognition of a purely technological possibility and the start of an avalanche of its broad socio-economic applications. This delay has many causes which we already discussed, e.g., after initial social distrust, some time must pass before that distrust turns into a *blind social fascination* once a technological hit becomes fashionable. Once it starts to work, the second positive feedback loop is much stronger and faster than the first one. But it can have very dangerous side-effects.

This blind social fascination is actually the autonomous force, incorrectly attributed by social philosophy to technology proper, it is precisely the source of the Heideggerian danger that "man will exalt himself and posture as the lord of the earth".

There are many examples of such blind social fascination. Let us look only at an example of such danger well understood by software specialists, probably missed as yet by philosophers of technology. Consider mobile telephony; the current trend is to integrate many functions in the mobile computer contained actually in any *mobile* (mobile telephony device). One of such functions is global positioning system (GPS); when it is integrated in a mobile, the position on Earth of the user of the mobile can be determined with great accuracy. This has obviously many advantages, and users would pay for this function, mobile manufacturers compete to improve this function, etc., a social fascination. But what if an ambitious minister of interior uses this social fascination to "posture as the lord of the earth" and to implement totalitarian control of people?

[6]Black actually patented this concept in 1928, published a paper on it in 1934.

For such reasons, it is clear that inputs from philosophy of technology might enrich software development and evaluation; the issue, how dangerous is too great accuracy of pinpointing every user of a mobile, cannot be considered as a purely technical or purely economic one, it might require special ethical discussion and legal safeguards. But philosophers of technology, in order to be useful in such a case, should know at which stage of technological development they must participate.

Therefore, let us examine possible stages in some more detail. We list these stages below:

1. Motivation – artistic urge or social demand.
2. Technology proper – actual construction or design of a prototype tool.
3. Testing and evaluation.
4. Transfer from academia to industry.
5. Design of mass production process.
6. Pre-marketing: promotion of demand.
7. Mass production and marketing.
8. Re-engineering based on consumer (user) remarks.
9. Design of new versions due to technological advancement and integration.

The list should not suggest that it is an almost linear[7] process, with few recursions. It is used only to shorten description, while in reality obviously there are many recursions, at each stage different actors are usually involved, multivariate choices have to be made, etc. (see, e.g., [15]).

These nine points only outline the typical stages; some might be omitted, some performed parallel. Stage 1 might be just an idea of a novelty, which I call artistic urge; or perception of future social demand; or realization of actual economic demand, not quite satisfied by market forces. Stage 2 is most important for technology creation and, whether in hardware or software, is not reducible to simple application of hard science; it is artistic, its main motivation is the joy of creation (if an engineer wants to make money, (s)he becomes a manager); this stage is most misunderstood by social constructivists who do not even notice its artistic motivation. Stage 3 is actually equally important: since stages 1 and 2 might be artistic, intuitive, their products must be thoroughly tested and evaluated. Moreover, testing occurs recursively also in other stages, e.g., after preparing a prototype for mass production. In hardware, the tests are very often of destructive character, such as crash tests of cars, just to determine the limits of safe use of new tools. In software, we also often abandon or re-engineer old versions after their tests and evaluation.

Thus, technology is *falsificationist* (in the sense introduced by Karl Popper, see [16]) in its everyday practice. If is a kind of irony, because postmodern sociology of science ridicules falsificationism, saying (with some reasons) that scientists do not try to disprove, only promote their theories; and Karl Popper defended his metaphysical position with regard to the evolution of science, while regarding technology as a mere application of science[8]. Meanwhile, tools are not theories and it is technology that is actually falsificationist, because it is not a mere application of science. This is consistent with (although not noted by) Rachel Laudan [18], who tried to find scientific revolutions of the type of Thomas Kuhn [19] in technology and reported that technological revolutions have quite different character, since technology is more pragmatic, less paradigmatic.

Stage 4 is especially difficult and stages 2 and 3 might be repeated in stage 4; we comment on the reasons in the next section. Naturally, it happens that new technology products (not so often essentially new) are developed directly in industrial laboratories; only then one can speak about factory-like production of knowledge, a favourite theme of postmodern sociology of science. But even then the concept of *techoscience* [14] is a misnomer, because science is paradigmatic, technology falsificationist, they differ essentially in their values and episteme, and in industrial production of knowledge there is a tension between them about the intensity and character of testing and evaluation. Stages 5 and 7 are typical for industrial civilization, and stay important also during informational revolution, though naturally change their character due to automation and robotization, and even more in the case of dematerialized software products. Most of classical philosophy of technology maintained that mass production – particularly Fordism – is the defining characteristics of modern technology, often without noting how information technology made classical Fordism obsolete.

Stage 6 – promotion of demand – must start parallel with preparation of mass production, because it might take more time. Stages 8 and 9 – re-engineering and design of new versions – often proceed parallel.

Now, when should a philosopher of technology participate in this process, to make the outcomes more socially controllable? This corresponds to the question of Langdon Winner [15]: "Where should a philosopher go to learn about technology?"[9] I can accept the argument that it is almost impossible for (her)him to participate in stages 1 and 2; but stage 3 starts relatively early, and the philosopher of technology might be most useful then, also might obtain important insights about the processes of technology creation. Moreover, since (s)he is worried about social

[7] "Linear" in the social science sense of being non-recursive; technologists would rather use "linear" in the sense of linearity of the mathematical model.

[8] Ironically, Karl Popper actually argued that technology does not use falsification [17]. However, his arguments were that engineers do not abandon their designs after falsifying them (obviously not true) and that technology does not use crucial experiments (also not true, much thought is devoted in technology how to devise critical experiments). Thus, his arguments show simply a lack of understanding of technology.

[9] My actual answer is: *philosopher should learn technology as a part of (her) his curriculum at university*, since more than fifty years ago I learned philosophy as a part of mine technological curriculum. But above I propose a less demanding answer.

consequences of technology, (s)he should take also an active part in stage 6.

4. The Difference between Academic and Industrial Knowledge Creation

In order to illustrate the difference of academic and industrial knowledge creation, I review here some results concerning so-called micro-theories of knowledge creation. The demands of knowledge based economy resulted recently in the emergence of many such micro-theories – concerning knowledge creation for the needs of today and tomorrow, as opposed to classical concentration of philosophy on macro-theories of knowledge creation on a long term historical scale. Historically, we could count the concept of *brainstorming* [20] as an early example of such micro-theories. Since 1990 we observe many such new micro-theories originating in systems science, management science and information science, beginning with the *Shinayakana systems approach* [21], the *knowledge creating company* and the *SECI* (socialization-externalization-combination-internalization) *spiral* [22], the *rational evolutionary theory of intuition* [23], the I^5 *(pentagram) system* [24], the *OPEC* (objectives-process-expansion-closure) *spiral* [25] and several others. All such recent micro-theories of knowledge creation processes take into account the interplay of tacit, intuitive, emotive, and preverbal aspects with explicit or rational aspects of knowledge creation, as well as the interplay between an individual and a group.

Additional results concerning micro-theories of knowledge creation were obtained also in the 21st Century COE Program Technology Creation Based on Knowledge Science at the Japan Advanced Institute of Science and Technology (JAIST). For example, the brainstorming process was represented as the *DCCV* (divergence-convergence-crystallization-verification) *spiral* [26] due to the research in this program. The concept of *creative space* [4] tries to provide a synthesis of such diverse micro-theories.

We shall not discuss here in detail the rational evolutionary *theory of powerful but fallible intuition* (see [4], [23], [27]). The introduction of a three-by three matrix *rational-intuitive-emotive* and *individual-group-humanity* knowledge used in [4] instead of two-by-two *explicit-tacit* and *individual-group* used as the basis of the *SECI spiral* in [22] makes it possible to generalize the *SECI spiral* into a network-like model of creative processes, called *creative space* (see Fig. 2).

The model of *creative space* consists of *nodes* – such as *Individual rationality* or individual rational knowledge – and *transitions*[10] between the nodes — such as *Internalization* from *Individual rationality* to *Individual intuition*. Note that the *SECI spiral* of [22] is essentially preserved

[10]Originally called *conversions* by Nonaka and Takeuchi [22], but knowledge is not lost when used, hence it cannot be converted; thus we prefer the more neutral term *transitions*.

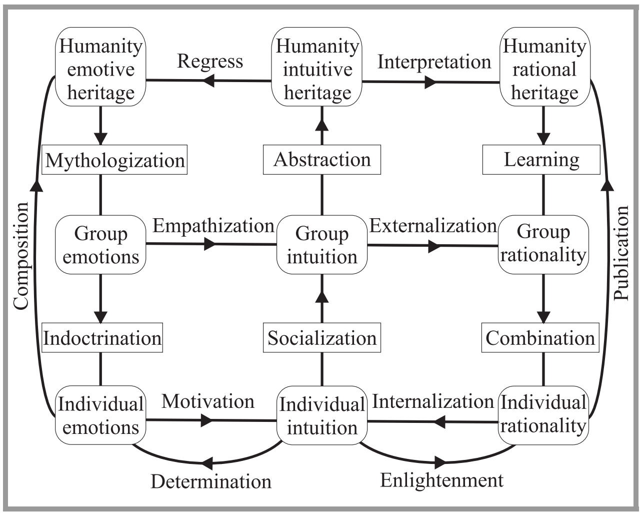

Fig. 2. Basic dimensions of creative space.

in the lower right-hand corner of Fig. 2; but creative space involves also many other transitions. For example, the upper left-hand corner of Fig. 2 represents [28] the theory of revolutionary scientific change in the form of the *ARME* (abstraction-regress-mythologization-emphatization) *spiral*, see [4] for a more detailed discussion.

Other dimensions can be added to the model of creative space and many other knowledge creation processes can be represented in the model. Knowledge management is naturally more interested in the processes of *normal* knowledge creation (as opposed to *revolutionary*; this distinction is due to Kuhn [19]). In [5], two types of normal knowledge creation processes are distinguished:

- *Organizational or industrial* processes in market or purpose-oriented knowledge creation, such as the *SECI spiral* of Nonaka and Takeuchi. Such processes are motivated mostly by the interests of a group and two other spirals of this type can be also represented in creative space; these are the *brainstorming DCCV spiral* [26] and the occidental counterpart of *SECI spiral*, the *OPEC spiral* of [25].

- *Academic* processes of normal knowledge creation, in universities and research institutes. Such processes are motivated mostly by the interests of an individual researcher. Three typical spirals of this type are distinguished as parts of *creative space* in [4]:
  - the *hermeneutic* (enlightenment-analysis-hermeneutic immersion-reflection) *EAIR spiral* of reading and interpreting scientific literature;
  - the *debating EDIS* (enlightenment-debate-immersion-selection) *spiral* of scientific discussions;
  - the *experimental EEIS* (enlightenment-experiment-interpretation-selection) *spiral* of performing experiments and interpreting their results.

We should note that all these three spirals begin with the transition *enlightenment* from *individual intuition* to *individual rationality* (called also variously *abduction*, *aha*, *eureka*, *illumination* – simply having an idea – and indicated in the bottom right-hand part of Fig. 2). Because of that, we can switch between these three spirals or perform them parallel. This is indicated in Fig. 3, where these three spirals are presented together as a *triple helix* of normal academic knowledge creation.

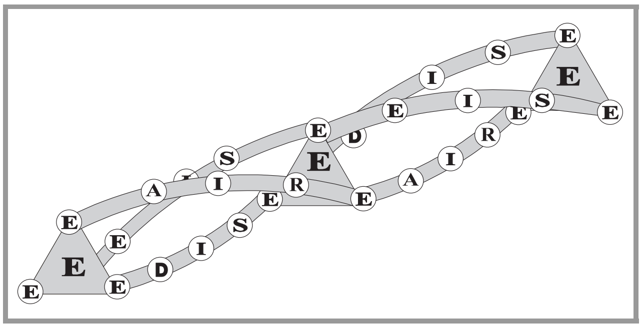

Fig. 3. The triple helix of normal academic knowledge creation.

Thus, academic knowledge creation processes are quite different than organizational knowledge creation; understanding their differences might help in overcoming the difficulty of cooperation between academia and industry. Alternatively, we could try to combine them, see below.

These three spirals contained in the triple helix do not exhaustively describe all what occurs in academic knowledge creation, but they describe most essential elements of academic research: gathering and interpreting information and knowledge, debating and experimenting. In fact, recent research including a questionnaire on creativity conditions in JAIST supported, both directly and indirectly, the conclusion that these elements are very important for academic knowledge creation, see [4], [29]. However, these spirals are *individually oriented*, even if a university and a laboratory should support them, e.g., the motivation for and the actual research on preparing a doctoral thesis is mostly individual. Moreover, the triple helix only describes what researchers actually do, it is thus a *descriptive* model. Obviously, the model helps in a better understanding of some intuitive transitions in these spirals and makes possible testing, which parts of these spirals are well supported in academic practice and which require more support; but it does not give clear conclusions *how to organize research*.

However, the three spirals of organizational knowledge creation mentioned before are important for practical knowledge creation, for innovations, particularly in industry and other purpose-oriented organizations. Unfortunately, they cannot be easily combined into a multiple helix like the triple helix, because they do not share the same elements. The main challenge is not only to combine these spirals between themselves, but also with the spirals of academic knowledge creation. This general challenge is difficult, but such a combination would be important for several reasons:

– combining these spirals might strengthen academic knowledge creation, because it would increase the role of the group supporting the individual research;

– combining these spirals might strengthen also industrial innovation and knowledge creation, because it always contains also some individual elements that should be explicitly accounted for;

– combining these spirals might help in the cooperation of industry with academic institutions in producing innovations, because it could bridge the gap between the different ways of conducting research in academia and in industry.

The idea of *Nanatsudaki model of knowledge creation processes* [5] tries to derive pragmatic conclusions from such analysis and synthesis, by combining seven spirals (objective setting OPEC, hermeneutic EAIR, socializing SECI, brainstorming DCCV, debating EDIS, roadmapping I-System [30], and experimenting EEIS) in an order useful for organizing large research projects, particularly for cooperation between academia and industry, see Fig. 4.

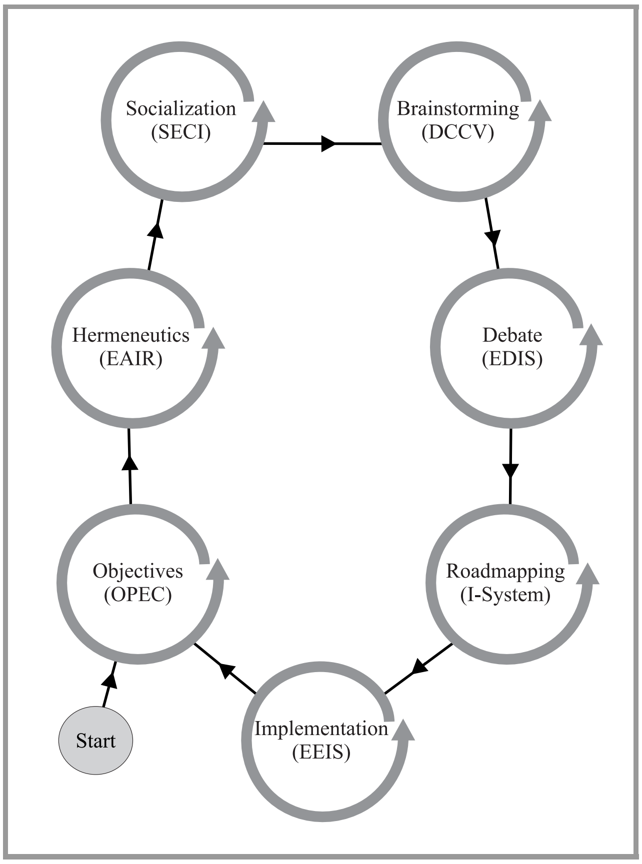

Fig. 4. Diagram of JAIST Nanatsudaki model (septagram of creative spirals).

The conclusion from this short discussion of the differences between academic and industrial knowledge creation is clear: they are essentially different, both by the difference between individual and group orientation and by the different character of typical processes used. We might try to overcome these differences, both in praxis and by suggesting models such as *Nanatsudaki septagram*, but overcoming these differences causes additional delays in technology development.

5. Changing Episteme

We understand here the concept of *episteme* in the sense of [31] – as *the way of creating and justifying knowledge characteristic for a given historical era*. However, if we live in time of a change of historical eras, then we should also observe a process of a change of the episteme. How does such process proceed?

During last stages of a former era, a change of the episteme is prepared by an accumulation of new concepts inconsistent with the old episteme and a following destruction of this old episteme. The new concepts inconsistent with the *modern episteme* that accumulated during the 20th century were, between others:

- relativity and relativism;
- indetermination and pluralism;
- feedback and dynamic systemic development;
- deterministic and probabilistic chaos, order emerging out of chaos;
- butterfly effect and change;
- complexity and emergence principle;
- computational complexity as a limit on cognitive power;
- logical pluralism;
- new theories of knowledge creation, etc.

This has led to a destruction of the modern episteme; in the second half of the 20th century, such a destruction resulted in a divergent development of the episteme of three cultural spheres of:

- basic, hard and natural sciences;
- social sciences and humanities;
- technology.

Thus, we should speak not about *two cultures* [32], but about *three distinct episteme* [11].

These cultural spheres adhere to different values, use different concepts and languages, follow different paradigms or underlying them hermeneutical horizons; *such differences increased gradually with the development of poststructuralism and postmodernism, while hard sciences and technology went quite different epistemic ways*.

Obviously, *technology cooperates strongly with hard and natural sciences*, as shown in Fig. 1; but there is an essential epistemic difference between these two spheres: hard and natural sciences are paradigmatic, while technology is not paradigmatic, rather pragmatic. However, both hard sciences and technology know for a long time (e.g., since [33]) that knowledge is constructed by humans, only they interpret this diversely.

Even if a hard scientist knows that all knowledge is constructed and there are no absolute truth and objectivity, he believes that scientific theories are *laws of nature discovered by humans* rather than *models of knowledge created by humans*. He values truth and objectivity as ultimate ideals; metaphorically, hard scientist resembles a priest.

A technologist is much more *relativist and pragmatic* in his episteme, he readily agrees that *scientific theories are models of knowledge*; but requires that these theories should be *as objective as possible*, tested in practice, he demands that they should be *falsifiable* (as postulated by Karl Popper [16]). Metaphorically, a *technologist resembles an artist* (see also [10]–[12]), also values tradition like an artist does, much more than a scientist.

Without discussing in further detail the observed differences between the episteme of these three cultural spheres and many actual examples of these epistemic differences – *science wars* in the last decade of the 20th century were a clear indication of them (see, e.g., [34]), we turn to other conclusions.

If we are living in times of an *informational revolution* and this revolution leads to a new civilization era, in which knowledge plays an even more important role than just information – thus we might call the new epoch the *knowledge civilization era* – then we might expect a formation of a new, integrated episteme characteristic for the new era. This usually occurs, as shown by Foucault [31], after the beginning of the new era. Naturally, the dates of beginnings of historical eras are conventional, reflect a given hermeneutical horizon, but are best defined by historians. Thus we follow the example of Fernard Braudel [35] who defined the long duration preindustrial era of the beginnings of capitalism, of print and geographic discoveries, as starting in 1440 with Gutenberg, and ending in 1760 with Watt. Following his example, we *select 1980* – the time when information technology was made broadly socially available by the introduction of personal computers and computer networks – *as the beginning date of the new era of knowledge civilization*, even though computers were used earlier[11].

[11] All these turning points were not new inventions, but improvements of older inventions that enabled, however, their broad social use. Print was known in China before Gutenberg, but it was inefficient, could not result in a mass production of books. Steam engine was known before Watt, but it tended to explode, could not be used broadly. Computers were known before Apple Co. produced first personal computer, but former computers were giant machines used only by specialists.

Thus, instead of three waves of [36] we speak about recent *three civilization eras*:

- *preindustrial civilization* (*formation of capitalism*) 1440–1760;
- *industrial civilization* 1760–1980;
- *knowledge civilization* 1980–2100+(?)

The date 2100+ means "at least until 2100" and is not only a simple prediction based on shortening periods of these eras (320–220–120?), it can be substantiated also differently, see [6].

The new episteme characteristic for the era of knowledge civilization must be an integration of the diverged epistemic positions of hard sciences, soft sciences and technology. An attempt of such integration was made, e.g., in [5]. However, here we shall quote only some elements that might help in the integration of the new episteme, namely, the *multimedia principle* and the *emergence principle*. These two principles were first formulated in [4], [5].

Multimedia principle: words are just an approximate code to describe a much more complex reality, visual and preverbal information in general is much more powerful and relates to intuitive knowledge and reasoning; the future records of the intellectual heritage of humanity will have a multimedia character, thus stimulating creativity.

Emergence principle: new properties of a system emerge with increased levels of complexity, and these properties are qualitatively different than and irreducible to the properties of its parts.

Both these principles might seem to be just common sense, intuitive perceptions; the point is that they are justified rationally and scientifically. Moreover, they go beyond and are in a sense opposed to fashionable trends in poststructuralism and the postmodern philosophy or sociology of science.

The multimedia principle is based on the technological and information science knowledge: as shown in the rational evolutionary theory of intuition [23], *a figure is worth at least ten thousand words*. The poststructuralist philosophy stresses the roles of *metaphors and icons*, but reduces them to *signs*, which is contrary to the emergence principle. Thus, the world is not constructed by us in a social discourse, as the poststructuralist and postmodern philosophy wants us to believe: *we observe the world by all our senses, including vision, and strive to find adequate words* when trying to describe our preverbal impressions and thinking *to communicate them in language*. Language is a shortcut in civilization evolution of humans, our original thinking is preverbal, often unconscious.

Multimedia principle originates in technology and has diverse implications for technology creation. *Information technology creation should concentrate on multimedia aspects of supporting communication and creativity. Technology creation starts essentially with preverbal thinking.*

The emergence principle is also partly motivated by technological experience. It stresses that new properties of a system emerge with increased levels of complexity, and *these properties are qualitatively different than and irreducible* to the properties of its parts. This might appear to be just a conclusion from the classical concepts of systems science, synergy and holism; or just a metaphysical religious belief. The point is that both such simplifying conclusions are mistaken. *Synergy and holism say that a whole is greater than the sum of its parts, but do not stress irreducibility. Thus, according to classical systemic reasoning, a whole is greater, but still explicable by and reducible to its parts.*

The best recent example of the phenomenon of emergence is the concept of software that spontaneously emerged in the civilization evolution during last fifty years. *Software cannot function without hardware, but is irreducible to and cannot be explained by hardware*. This has also some importance for the metaphysics of the absolute, because it is also a negation of the arguments of creationists who say that irreducible complexity could not emerge spontaneously in evolution.

Both multimedia principle and emergence principle might be interpreted as having some metaphysical character, in the same sense as Karl Popper admitted [16] that his falsification principle has metaphysical character. The emergence principle, however, is not a metaphysical religious belief, because it can be justified rationally and scientifically (see [4], [5]) – even if it might have serious metaphysical consequences.

Based on the concepts presented above, we might turn back to the issue of basic explanations of development of science and technology. People, motivated by curiosity and aided by intuition and emotions, formulate hypotheses about properties of nature and of human relations; they also construct tools that help them to deal with nature or with other people; together, we call all this knowledge (see also [37]). People test and evaluate the knowledge constructed by them by applying it to reality: perform destructive tests of tools, devise critical empirical tests of theories concerning nature, apply and evaluate theories concerning social and economic relations. Such a process can be represented as a general spiral of evolutionary knowledge creation [5], [34], see Fig. 5.

We observe reality and its changes, compare our observations with human intellectual heritage (*Observation*). Then our intuitive and emotive knowledge helps us to generate new knowledge (*Enlightenment*); we apply new knowledge to existing reality (*Application*), obtain some changes of reality (*Modification*). We observe them again and modified reality becomes existing reality through *Recourse*; only the positively tested knowledge, resilient to falsification attempts, remains an important part of human heritage (*Evaluation*); this can be interpreted as an objectifying, stabilizing feedback.

Thus, *nature is not only the effect of construction of knowledge by people, nor it is only the cause of knowledge: it is both cause and effect in a positive feedback loop, where more knowledge results in more modifications of nature and*

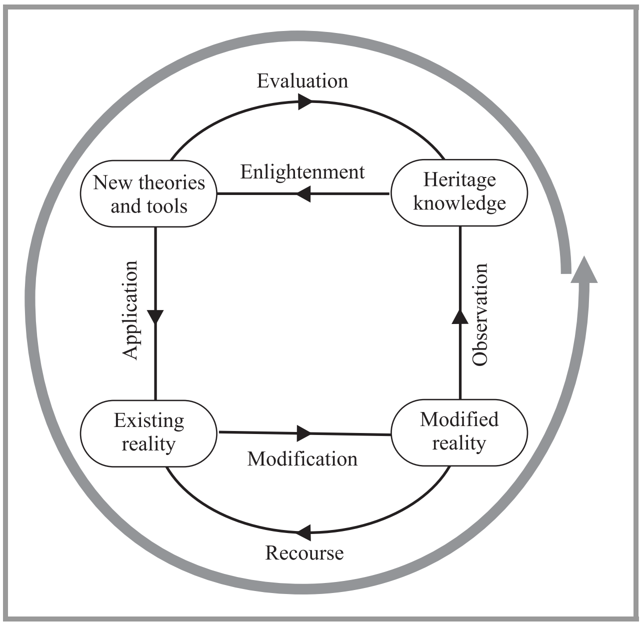

Fig. 5. The general OEAM spiral of evolutionary knowledge creation.

more modifications result in more knowledge. The overall result is an avalanche-like growth of knowledge, although it can have slower normal and faster revolutionary periods. This avalanche-like growth, if unchecked by stabilizing feedbacks, beside tremendous opportunities creates also diverse dangers, usually not immediately perceived but lurking in the future.

Moreover, we should select knowledge that is as objective as possible (even if absolute objectivity is impossible; which we know since Heisenberg [38]) because avalanche-like growth creates diverse threats: we must leave to our children best possible knowledge in order to prepare them for dealing with unknown future.

6. What New Topics Can We List for Philosophy of Technology

Science, particularly soft science, is paradigmatic; this concerns also philosophy of technology, no matter whether we would classify philosophy as science or as a separate part of human knowledge. *Philosophy of technology* follows certain exemplars: it is general, sees technology as a socio-economic system of producing and utilizing products of technology; sometimes accuses this system of being uncontrollable, or developing without taking into account humanistic values; or even being unethical; is historically oriented, concentrates on *ex post* evaluation of results of technological development – and *avoids learning details of technological development*. This concerns even the most technology-friendly, new approaches to philosophy of technology, such as Don Ihde [39] or Peter-Paul Verbeek [40].

We have seen that this paradigm is self-reinforcing: if you don't want to learn details of a process and the process has internal, large delays, then you will consider this process uncontrollable; if you judge that some process is uncontrollable, then you do not think it is worth learning its' details. We have seen that this paradigm is just opposite to the praxis of software development and evaluation which – despite inevitable delays – concentrates practically on the control of an important technological process.

Therefore, a way of changing the paradigmatic attitude of philosophy of technology is to invite some such philosophers to participate in software development and evaluation; if they want to have an impact on contemporary technology development, to a large extent determined by software, it is an invitation they could not refuse without risking becoming outdated and sterile. And they can enrich software evaluation, contribute to its' ethical and sociological dimensions.

However, when participating in software evaluation, philosophers of technology will inevitably learn more about software, about its evaluation methods, about the falsificationist approach of technology to knowledge creation – thus they will be forced to revise their paradigm. Thus, inviting philosophers to participate in software evaluation is not only in the interest of the latter; it is also in the interest of better understanding the character of informational revolution and knowledge civilization era.

If the philosophers of technology learn more about informational revolution, they might be also helpful in resolving new conflicts and counteracting new dangers related to the knowledge civilization era. We shall discuss here shortly only two such issues.

First is *the conflict between the individual property of knowledge, supported by public property of the human intellectual heritage, and the corporate property of knowledge* that attempts to subjugate the individual knowledge of employees and to privatise the human intellectual heritage. This conflict is inevitable if knowledge becomes the main productive resource. Old arguments supporting privatization (e.g., so called tragedy of commons: common use of a pasture leads to a degradation of the common resource) are used to justify the actions of the corporate side, but knowledge has different properties than other productive resources, it is not degradable, its use results in an increase, not a decrease of the jointly held knowledge. Thus, it is better for society if knowledge remains public resource, while many corporate companies realized long ago that it is in their interest to privatize this public property. This conflict is already perceived, see [41], and academy strikes back by promoting the idea of open access and demanding that all results of research financed by public resources should be freely accessible in net portals. However, this is only the beginning of a conflict that might become the defining one for the knowledge civilization era.

The second is an *actual threat of computer and robot domination of people*. Such a threat was a natural subject of science fiction; on the other hand, some excellent books, e.g., [42], have shown that human mind cannot be duplicated by a classical computer intelligence. However, while the rational evolutionary theory of intuition [23] supports such a conclusion, it also shows that the difference, although tremendous, is quantitative (e.g., a figure is worth at least ten thousand words). Thus, if the Moore law [43] holds for another two or three decades, new aspects of the intelligence of computers might emerge and it might start to be comparable even to the intuitive and emotive intelligence of humans. Moreover, already now robots are being used as weapons; what about their use by terrorists or organized crime? Thus, we should not regard this issue as a distant, science fiction question, but already now start debates how to counteract these dangers.

7. Conclusions

The main points of this paper are:

- Technology development process is complex, has many stages and includes many delays, in historical evidence amounting sometimes to fifty years.
- When seen holistically from outside, such a process is apt to appear uncontrollable (called also autonomous or deterministic by philosophy of technology) – but this is only a matter of perspective.
- When seen from inside and in technological detail, such a process is very much controllable, and several technological disciplines concentrate on the ways of controlling such processes.
- Software development and evaluation is one of such processes, very important for future technology development.
- It is worthwhile to invite philosophers of technology to participate in software evaluation; this might even contribute to the change of the paradigm of philosophy of technology.
- Philosophy of technology should be also aware of new conflicts and dangers related to the knowledge civilization era.

A general conclusion is also that we need paradigm changes and essentially new approaches to many issues, such as software development and evaluation versus philosophy of technology, in the time when informational revolution results in a transition towards knowledge civilization.

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